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The Impact of Kaluza-Klein Excited W Boson on the Single Top at LHC and Comparison with other Models

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Abstract

We study the s-channel single top quark production at the LHC in the context of extra dimension theories, including the Kaluza-Klein (KK) decomposition. It is shown that the presence of the first KK excitation of W gauge boson can reduce the total cross section of s-channel single top production considerably if $M_{W_{KK}} \sim 2.2$ TeV (3.5 TeV) for 7 TeV (14 TeV) in proton-proton collisions. Then the results will be compared with the impacts of other beyond Standard Model (SM) theories on the cross section of single top s-channel. The possibility of distinguishing different models via their effects on the production cross section of the s-channel is discussed.

1 Introduction

The top quark is the heaviest particle yet discovered and might be the first place in which new physics effects could appear. The properties of the top quark could reveal information regarding flavor physics, the electroweak symmetry breaking mechanism and physics beyond the Standard Model(SM). For this reason, the search for signal top production is one of the major goal of the Tevatron and Large Hadron Collider (LHC)[1]. The top quark production at Tevatron has been extensively studied. So far no hint for the beyond the SM has been detected in Tevatron[2]. With the increase in the number of the top

quark events at the Tevatron, the experimental uncertainties are expected to be further reduced. Thus, the comparison between the observed top quark production properties and more precise theoretical calculations will be a new probe for possible existence of the new physics. At the LHC, top quarks are produced primarily via two independent mechanisms: The dominant production mechanism is the QCD pair production processes $q\bar{q} \rightarrow t\bar{t}$, $gg \rightarrow t\bar{t}$ and second is single top production. Single top quarks at the LHC are produced via SM in three kinematically different channels. The s-channel W^* production, $q\bar{q}' \rightarrow W^* \rightarrow t\bar{b}$ [3], the t-channel W-exchange mode, $bq \rightarrow tq'$ [4] and the tW production [5]. Since the cross section of single top production is smaller than the cross section of $t\bar{t}$ production and the final state signals suffer from large background events, the observation of the single top events is even more challenging than $t\bar{t}$. It is expected that sufficient integrated luminosity and improved method of analysis will eventually achieve detection of single top events at the LHC.

The process $q\bar{q}' \rightarrow W^* \rightarrow t\bar{b}$, compare to the single top production via t-channel can be reliably predicted and theoretical uncertainty in the cross section is only about a few percent [6]. The statistical uncertainty in the measurement of cross section for this process at the LHC will be about 5.4% with an integrated luminosity of $30fb^{-1}$ [7]. At the leading order, the cross sections of production for all three processes are proportional to the Cabibbo-Kabayashi-Maskawa (CKM) matrix elements. However, the LHC can precisely measure single top production cross sections, and the CKM matrix elements could be measured down to the less than one percent error at the ATLAS detector [7]. Therefore, it is worthwhile to investigate the effects of physics beyond SM on single top quark production. Search for new physics via single top production has been already investigated in [8, 9, 11].

In this paper, we study the effects of extra dimension theories on the single top production via $q\bar{q}' \rightarrow W^* \rightarrow t\bar{b}$ at the LHC. In extra dimension theories,

if the gauge fields of the SM propagate in the bulk of the extra dimension then they will have Kaluza-Klein (KK) excitations that can couple to the SM fermions. The masses of KK excited gauge boson will be proportional to inverse radius of compactification. If the inverse of radius of compactification is in order of TeV scale or less, phenomenological effects of these states in ongoing colliders will be remarkable [8]. There are various experimental bounds on these masses which arise from precision electroweak tests, cosmological constraints and low energy observables [12]. The lower bound on the masses of the first excited of gauge boson obtained from W' searches in $p\bar{p}$ collision at Tevatron indicate that they must lie above $\simeq 915$ GeV [13]. If the fundamental Planck scale as a cutoff of the SM physics is at around few TeV, We expect that there will be higher-dimensional operators suppressed by the cutoff scale. For operators which respect symmetries of SM, the constraints come from the electroweak precision tests. For example, Higgs mass is limited by constraints which come from the requirements of vacuum stability. It is shown [14] that the effects of the higher dimensional operators on the Higgs mass are significant. However, in theories with extra dimensions, phenomenological constraints from CP violations, FCNC and electroweak precision measurements give a bound on cutoff in order of ~ 10 TeV [15, 16]. In all of these analyses, it is assumed that the only new physics beyond SM come from the KK excitations of SM fields. Note that the gravity induced processes will affect on electroweak observables and change lower bound on masses of KK excitations of SM fields but will not significantly affect on single top production [17]. For this reason, we ignore the gravity effects in our analysis. As it is mentioned above, precision electroweak fits can significantly affect on lower bound of scale of KK excitations fields (M_c). In the literature, it has been shown [18] that these bounds are at the order of TeV scale. In light of these studies, we assumed that lower bound on KK excitations of gauge fields is at the order of TeV scale.

In this paper, we study the contribution of the first excitation KK mode of W which denoted by W_{KK} , on the s-channel single top production at LHC. It should be noted that for the high mass region of the W' , its contribution to the t-channel and tW -channel cross section are very small to be observed [9]. The W' in t-channel process is space-like and in tW -channel is real but the involved W boson in the s-channel is time-like.

The rest of this paper is organized as follows: In the next section, we summarize the effect of excited KK W state on the single top production. In section 3 we first evaluate the effect of excited KK mode of W on the s-channel single top production at LHC and compare it with results which arise from other alternative new physics models. In this section, we discuss the degeneracies between these models and survey the possibility of solving this degeneracies. Our conclusions are given in section 4.

2 KK excited W and its effects at LHC

In this section, we briefly describe the model and study effects of KK excited W on single top production at LHC.

In this paper, we consider a simple extension of the SM to 5 dimension(5D) which was assumed as a part of more fundamental underlying theory [19]. Note that gauge theories in more than 4-dimensions are non-renormalizable and should be treated as low energy effective theories below some cutoff Λ [20]. As SM fermions and Higgs carry gauge quantum numbers, they cannot propagate in extra dimensions unless the corresponding gauge fields also propagate in extra dimensions. On the other hand, SM fermions and Higgs may still be localized in 4 dimensions even if gauge fields propagate in extra dimensions. In this paper, we suppose SM gauge fields propagate in extra dimensions while fermions and Higgs live on 3-brane. Another case which all SM fields live in the same extra dimensions are strongly

constrained by electroweak precision data [20, 21]. As is mentioned earlier, we do not consider gravity induced processes in our analysis. Because they have negligible contributions.

In this model, we consider one extra dimension compactified on a circle with radius R . The coordinate are denoted as $x_M = (x_\mu, y)$, where $M = 0, 1, 2, 3, 5$, $\mu = 0, 1, 2, 3$ and $y = 5$ is the coordinate in the direction of the extra dimension. The compactification means that the points y and $y + 2\pi R$ are identified. As it is mentioned, we suppose that SM gauge fields live in 5D and so we can expand gauge fields with a Fourier decomposition along with the compact dimension,

$$\begin{aligned}\Phi_+(x_\mu, y) &= \sum_{n=0}^{\infty} \cos \frac{ny}{R} \Phi_+^{(n)}(x_\mu), \\ \Phi_-(x_\mu, y) &= \sum_{n=1}^{\infty} \sin \frac{ny}{R} \Phi_-^{(n)}(x_\mu),\end{aligned}\tag{1}$$

note that the fifth dimension y is compactified on the orbifold S^1/Z_2 with two 4D boundaries at $y = 0$ and at $y = \pi R$. In the above formula Φ_\pm^n are the KK excitations of the 5D gauge field and the gauge fields have defined to be even or odd under the Z_2 -parity, i.e $\Phi_\pm(y) = \pm \Phi_\pm(-y)$. After integrating over the fifth dimension, zero modes contain a 4D gauge field. In this model, SM gauge fields live in 5D bulk, while the SM fermions and Higgs doublets, can either live in the bulk or be localized on the 4D boundaries. As a result, the fermions and Higgs doublet couple to the KK excited gauge bosons only if they are localized on the 4D boundaries. After integrating over the fifth dimension, the effective four dimensional Lagrangian for charged electroweak sector can be obtained,

$$\mathcal{L}^{ch} = \sum_{a=1}^2 \mathcal{L}_a^{ch}\tag{2}$$

where

$$\begin{aligned}\mathcal{L}_a^{ch} &= \frac{1}{2}m_W^2 W_a \cdot W_a + \frac{1}{2}M_c^2 \sum_{n=1}^{\infty} n^2 W_a^{(n)} \cdot W_a^{(n)} \\ &- g W_a \cdot J_a - g \sqrt{2} J_a^{KK} \cdot \sum_{n=1}^{\infty} W_a^{(n)},\end{aligned}\quad (3)$$

and $m_W^2 = g^2 v^2/2$, the weak angle θ is defined by $e = g s_\theta = g' c_\theta$, while the currents are

$$\begin{aligned}J_{a\mu} &= \sum_{\psi} \bar{\psi}_L \gamma_\mu \frac{\sigma_a}{2} \psi_L, \\ J_{a\mu}^{KK} &= \sum_{\psi} \varepsilon^{\psi_L} \bar{\psi}_L \gamma_\mu \frac{\sigma_a}{2} \psi_L.\end{aligned}\quad (4)$$

Note that for ψ_L living in the bulk ε^{ψ_L} is 0 and for fermions which are living in 4D will be 1.

The coupling of KK excited W to our model is determined in terms of Fermi coupling G_F up to corrections of $\mathcal{O}(m_Z^2/M_c^2)$ [17]. For $M_c \sim 1$ TeV the $\mathcal{O}(m_Z^2/M_c^2)$ effects are negligible for single top production and therefore we do not consider these effects in our calculations. We have ignored the mixing of the W with W_{KK} which is also an $\mathcal{O}(m_Z^2/M_c^2)$ effects. Therefore, in our model W_{KK} decays only to SM particles. As a result, to calculate the cross section of $pp \rightarrow t\bar{b}X$, we only need to take into consideration the couplings of the SM fermions to the KK excitations of the electroweak gauge bosons and their unknown mass of W_{KK} .

The cross section of $pp \rightarrow t\bar{b}X$ is given by

$$\sigma(pp \rightarrow t\bar{b}X) = \sum_{q\bar{q}'} \int dx_1 dx_2 [q(x_1) \bar{q}'(x_2) + q(x_2) \bar{q}'(x_1)] \hat{\sigma}(q\bar{q}' \rightarrow t\bar{b}). \quad (5)$$

where $q(x_i)$ is structure function of u or c quarks and $\bar{q}'(x_i)$ is structure function of \bar{d} or \bar{s} quarks. x_1 and x_2 are the parton momentum fractions. The partonic cross section takes the form [9]:

$$\hat{\sigma} = \sum_{q,q'} \frac{\pi\alpha_W^2}{6} |V_{tb}|^2 |V_{qq'}|^2 \frac{(\hat{s} - M_t^2)^2 (2\hat{s} + M_t^2)}{\hat{s}^2} \left[\frac{1}{(\hat{s} - m_W^2)^2 + \gamma_W^2 m_W^2} + \right. \quad (6)$$

$$+ \frac{2(\hat{s} - m_W^2)(\hat{s} - M_{W_{KK}}^2) + \gamma_W^2 \Gamma_{W_{KK}}^2}{((\hat{s} - m_W^2)^2 + \gamma_W^2 m_W^2)((\hat{s} - M_{W_{KK}}^2)^2 + \Gamma_{W_{KK}}^2 M_{W_{KK}}^2)} +$$

$$\left. + \frac{1}{(\hat{s} - M_{W_{KK}}^2)^2 + \Gamma_{W_{KK}}^2 M_{W_{KK}}^2} \right]$$

where γ_W is width of W gauge boson, $\alpha_W = g^2/(4\pi)$ and $\hat{s} = x_1 x_2 S$ is parton center of mass energy while S is the pp center of mass energy. Width of the W_{KK} is given by [22]

$$\Gamma_{W_{KK}} \approx \frac{2M_{W_{KK}}}{M_W} \gamma_W + \frac{2M_{W_{KK}}}{3M_W} \gamma_W \cdot X,$$

$$X = \left(1 - \frac{M_t^2}{M_{W_{KK}}^2}\right) \left(1 - \frac{M_t^2}{2M_{W_{KK}}^2} - \frac{M_t^4}{M_{W_{KK}}^4}\right). \quad (7)$$

Note that W_{KK} will have the same decays as the W boson but in addition it can also decays to top-bottom pair which is kinematically forbidden for W boson.

3 Numerical results

In this section, we study the effects of KK excitation of W gauge boson on the cross section of production $pp \rightarrow t\bar{b}X$ at LHC. We first discuss the experimental bounds on mass of KK excited W . We then present our result and discuss the possibility of detection of large extra dimensions at LHC via single top. We compare our result with other new physics beyond SM and their effects on production $pp \rightarrow t\bar{b}X$ at LHC. We then discuss the possibility of solving degeneracy between different new physics models.

As it is discussed in previous section, there exists two kinds of experimental constraints on the mass of KK excited W . First kind of constraints

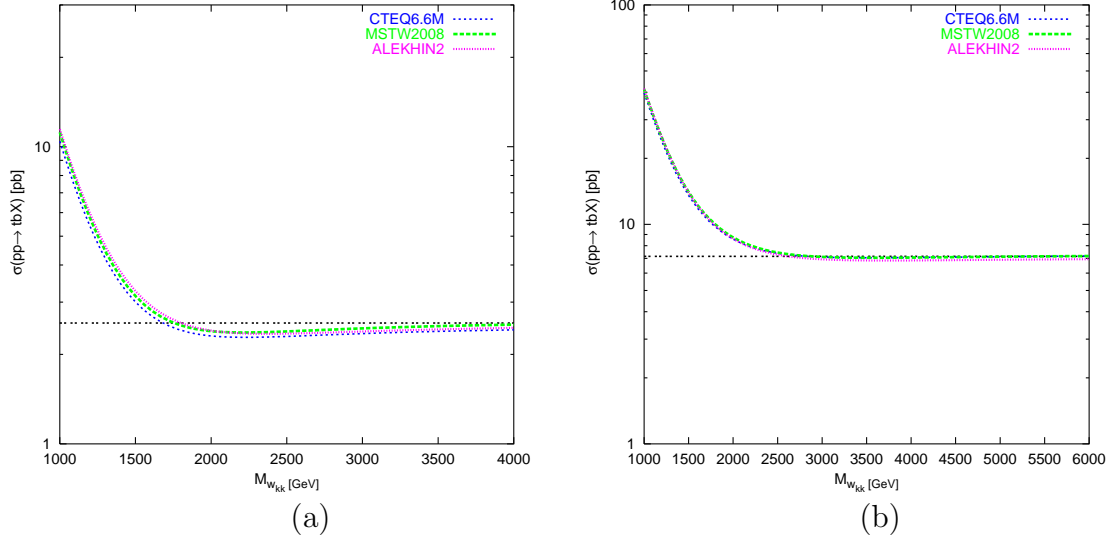


Figure 1: a) $\sigma(pp \rightarrow t\bar{b}X)$ versus $M_{W_{KK}}$, the mass of the first KK excitation mode of W . In this figure, we have set $\sqrt{S} = 7$ TeV. The horizontal line at 2.55 pb depicts SM prediction for this process at $\sqrt{S} = 7$ TeV. The dotted (blue) curve, the dashed (green) curve and small dotted (pink) curve respectively correspond to CTEQ6.6M [24], MSTW2008 [25] and ALEKHIN2 [26] structure functions. b) Similar to Fig. a except that $\sqrt{S} = 14$ TeV. The horizontal line at 7 pb depicts SM prediction for this process at $\sqrt{S} = 14$ TeV.

arises from indirect search for large extra dimensions. Model dependent limits can be placed on the masses of KK excitation SM fields from precision electroweak test, astrophysics (*e.g.*, star cooling), cosmology (*e.g.*, expansion rate of the universe) and low energy experiments (*e.g.*, CP violation and FCNC processes)[12, 17, 18]. Another kind of constraints comes from direct search of W' at existing colliders. A null result for a search of W' in single top production at Tevatron indicate that mass of W' must lie above 915 GeV [13]. In our analysis, we consider these bounds on mass of the first KK excitation mode of W .

In this paper, we study the effects of first KK excitation of W on s-

channel single top production at LHC. In [23], it has been shown that in 7 TeV collisions with small amount data, a W' boson with a mass above the present experimental limits could be found. For example, with the integrated luminosity of 1 fb^{-1} , a W' boson with the mass of 3 TeV can be reached.

In Figure. 1, we display the cross section of $pp \rightarrow t\bar{b}X$ versus $M_{W_{KK}}$ (the mass of the first KK excitation mode of W). To calculate $\sigma(pp \rightarrow t\bar{b}X)$, we have used the CTEQ6.6M [24], MSTW2008 [25] and ALEKHIN2 [26] structure functions. The dotted (blue) curve, the dashed (green) curve and small dotted (pink) curve respectively correspond to CTEQ6.6M, MSTW2008 and ALEKHIN2 structure functions. As it is seen in this figure, different structure functions do not affect on the value of $\sigma(pp \rightarrow t\bar{b}X)$ more than 1%. In Fig.(1. a), we have set $\sqrt{S} = 7 \text{ TeV}$ and a SM cross section of 2.55 pb for the $\sigma(pp \rightarrow t\bar{b}X)$ is obtained. The horizontal line in this figure depicts SM prediction for this process. In Fig.(1. b), as explained in the caption, we have set $\sqrt{S} = 14 \text{ TeV}$. In the centre of mass of energy 14 TeV, leading order SM cross section of $pp \rightarrow t\bar{b}X$ have been obtained 7 pb. The vertical line at 915 GeV shows a lower bound on mass of KK excitation of W which comes from null result for W' search at Run IIa of Tevatron [13]. In Fig.1, there exists a peak at areas that $M_{W_{KK}}$ is smaller than direct lower bound. This is because of the momentum of the s-channel resonance is time-like which leads to large interference with SM amplitude. In Fig. 1, we observe that the presence of W_{KK} can decrease total cross section. For better study of this effect, we consider the relative change in cross section which is given by

$$R = \frac{\Delta\sigma}{\sigma_{SM}} = \frac{\sigma - \sigma_{SM}}{\sigma_{SM}}. \quad (8)$$

where σ is total cross section in the presence of W_{KK} . The relative change in cross section of the single top production at LHC are shown in Fig. 2. In this figure, we display relative change in cross section versus $M_{W_{KK}}$ for $\sqrt{S} = 7 \text{ TeV}$ and $\sqrt{S} = 14 \text{ TeV}$. The horizontal cyan (gray) lines correspond

to $\pm 5\%(\pm 10\%)$ uncertainty in the measurement of $\sigma(pp \rightarrow t\bar{b}X)$. Fig. 2 demonstrates that the effect of presence of W_{KK} for $M_{W_{KK}} > 1500$ GeV can be destructive. Notice that with increasing center of mass energy, deviation from SM cross section decreases. As it was mentioned, the ATLAS detector, can measure cross section for this process with statistical uncertainty of 5.4% [7]. After integrated luminosity of $30 fb^{-1}$, deviation more than 5% from SM cross section can allude to beyond SM physics. Because the cross section of the s-channel single top quark is proportional to the $|V_{tb}|^2$, it provides the possibility to measure V_{tb} element of CKM matrix directly [27]. Therefore, from the measurement of the cross section of s-channel smaller than the SM prediction one may conclude that $|V_{tb}| < 1$ and this could be interpreted as evidence for the presence of the new quark generation mixed with the third family. However, the result of this paper clearly shows that the measurement of the s-channel cross section smaller than the SM prediction would not necessarily indicate the evidence for extra family and it can be due to a new charged heavy gauge boson. Now suppose that a deviation of more than 5% is observed in the production cross section of s-channel single top. Can we distinguish between different beyond SM theories by applying these results? In the following, we study this problem with comparison of our result with other beyond SM effects.

First we compare our result with Littlest Higgs Model(LH) correction to s-channel single top cross section. The relative corrections of the LH model to the cross section $\sigma(pp \rightarrow t\bar{b}X)$ at the LHC are shown in Fig. 3. These curves have been borrowed from Figs. 1 and 4 of [30]. In these figures, the authors have been considered that $\Delta\sigma(pp \rightarrow t\bar{b}X) = \sigma_{LH} - \sigma_{SM}$, $f = 1.0$ TeV and $c(s = \sqrt{1 - c^2})$ is the mixing parameter between $SU(2)_1$ and $SU(2)_2$ gauge bosons and the mixing parameter $x_L = \lambda_1^2/(\lambda_1^2 + \lambda_2^2)$ comes from the mixing between the SM top quark t and the vector-like top quark T , in which λ_1 and λ_2 are the Yukawa coupling parameters. The curves have been shown

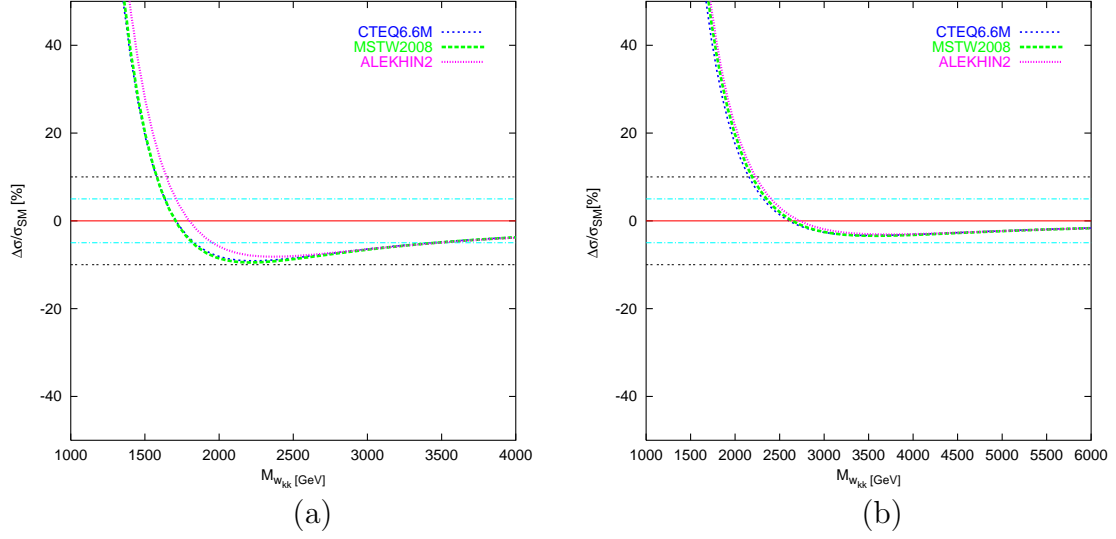


Figure 2: a) $\Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ versus $M_{W_{KK}}$, the mass of the first KK excitation mode of W . In this figure, we have set $\sqrt{S} = 7 \text{ TeV}$. The dotted (blue) curve, the dashed (green) curve and small dotted (pink) curve respectively correspond to CTEQ6.6M [24], MSTW2008 [25] and ALEKHIN2 [26] structure functions. b) Similar to Fig. a except that $\sqrt{S} = 14 \text{ TeV}$. The horizontal cyan (gray) lines correspond to $\pm 5\%(\pm 10\%)$ uncertainty in the measurement of $\sigma(pp \rightarrow t\bar{b}X)$.

with three values of the mixing parameters x_L and x_λ . Considering the constraints of the electroweak precision data on these free parameters, they will be assumed $f \geq 1\text{TeV}$, $0.4 \leq x_L \leq 0.6$ and $0 < c \leq 0.5$ [30].

From Fig. (3-a), we can see that the contributions of the LH model to single top production are very smaller than KK-excited W . The effect of LH model to s-channel single top production might be destructive but at most up to 1.4% for $x_L = 0.6$. This value is very smaller than precision of ATLAS detector with $30fb^{-1}$ data. Fig. (3-b) shows the relative correction $R_W = \Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ as a function of the mass new gauge boson W_H in the context littlest Higgs models for three values of the mixing parameters c . The value of the relative correction parameter R_W is in the range of $1.5\% \leq R_W \leq 90\%$. As it can be seen in this figure the effects of the new gauge boson W_H to the s-channel process for single top production is always constructive and we can distinguish between LH model with our model for some areas in parameters space ($M_{W'} > 2200 \text{ GeV}$).

Another beyond SM theory which we are going to consider is $SU(3)$ simple group model. The relative corrections of the $SU(3)$ simple group model to the cross section $\sigma(pp \rightarrow t\bar{b}X)$ at the LHC has been shown in Fig. 4. These curves have been borrowed from Figs. 2 and 5 of [30]. In these figures, it is assumed that $\Delta\sigma(pp \rightarrow t\bar{b}X) = \sigma_{SU(3)} - \sigma_{SM}$, $f = 1.0 \text{ TeV}$ Where $f = \sqrt{f_1^2 + f_2^2}$. The curves have been shown with three values of free parameters t_β where $t_\beta = \tan\beta = f_2/f_1$.

From Fig. (4-a), we can see that the contributions of the $SU(3)$ simple group model to single top production are larger than those of the LH model. The $SU(3)$ simple group model has negative contributions to single top production at the LHC and the maximum deviation from SM is 7.5% which is for the case of $x_\lambda = 4$. For $f = 1 \text{ TeV}$, $x_\lambda \geq 3$, and $1 \leq t_\beta \leq 5$, the absolute values of the relative correction for s-channel, is in the ranges of $3.7\% \sim 7.5\%$. Fig. (4-b) shows the relative correction $R_W = \Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ as a func-

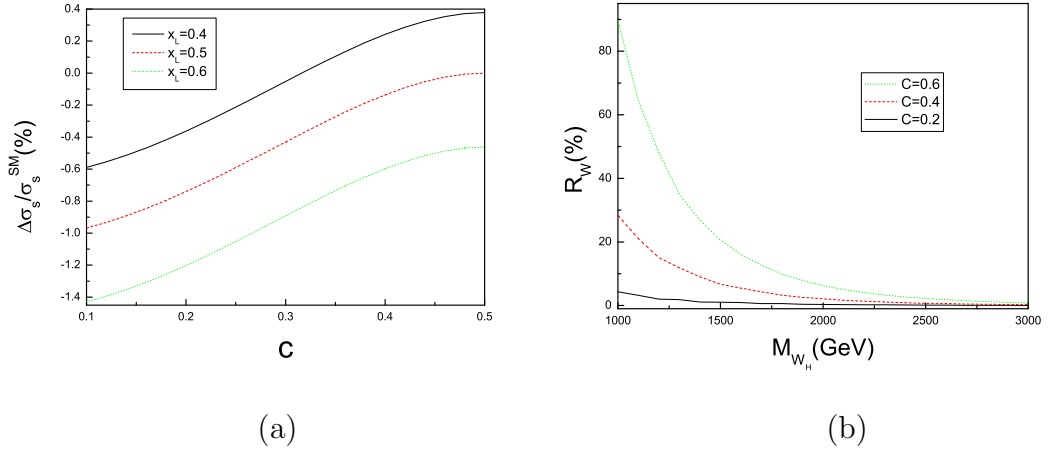


Figure 3: a) $\Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ versus mixing parameter c in the context of littlest Higgs models for $f = 1$ TeV and different values of the mixing parameter x_L . b) $R_W = \Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ versus M_{W_H} in the context of littlest Higgs models for three values of the mixing parameters c . These curves have been borrowed from Figs. 1 and 4 of [30].

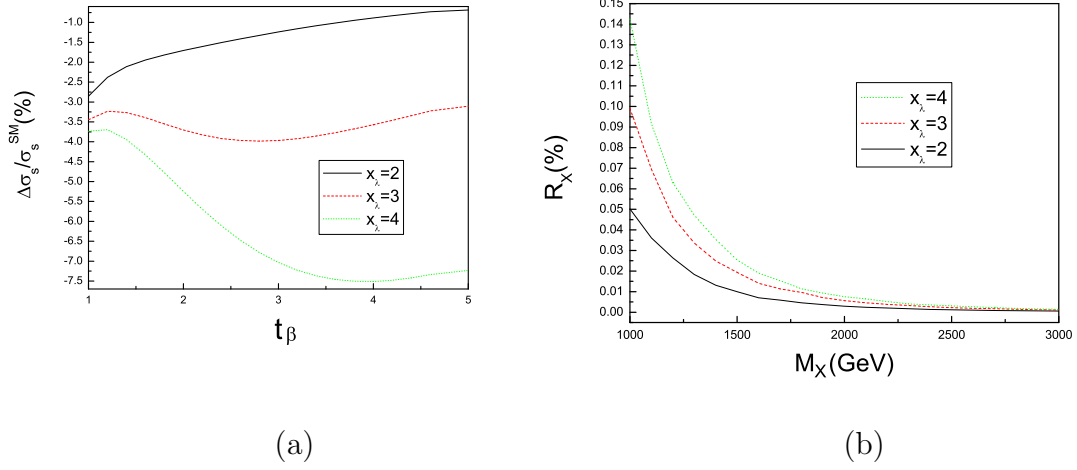


Figure 4: $\Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ versus the mixing parameter t_β in the context of $SU(3)$ simple group model for $f = 1$ TeV and different values of the mixing parameter x_λ . b) $R_W = \Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ versus M_X in the context of $SU(3)$ simple group model for $t_\beta = 3$ and three values of the mixing parameter x_λ . These curves have been borrowed from Figs. 2 and 5 of [30].

tion of the mass new gauge boson W_X in the context of $SU(3)$ simple group model for t_β and three values of the mixing parameters x_λ . The value of the relative correction parameter R_X is in the range of $0\% \leq R_X \leq 0.15\%$. Thus, the effects of the new gauge boson W_X on the s-channel single top production might not be detected at LHC.

In the context of unparticle physics, SM fields can interact with scalar, vector and tensor unparticles. The differential cross-sections of single top production by considering these three types of the unparticles have been presented in [33]. Contributions of unparticle physics to the cross section $\sigma(pp \rightarrow t + jet)$ at the LHC are shown in Fig. 5. Data for $\Delta\sigma(pp \rightarrow t + jet)$ have been taken from Figs. 3 and 4 of [33].

Figs. 5-a and b, show $\Delta\sigma(pp \rightarrow t + jet)/\sigma_{SM}$ versus the scale dimension

d_u in the context of unparticle physics for $\Lambda = 1$ TeV, $\lambda_0 = \lambda_1 = \lambda_2 = 1$ and $c_v = c_a$ at 14 TeV where λ_i are dimensionless effective couplings labeling scalar, vector and tensor unparticle operators. c_v and c_a represent vector and axial vector coupling unparticle, respectively. The solid violet curve corresponds to scalar unparticle, the dotted red curve corresponds to vector unparticle and the dashed cyan curve corresponds to tensor unparticles. With the large integrated luminosity value at LHC, $L = 10^5$ pb $^{-1}$, we see that about 100 events are possible for both vector and scalar mediated processes with $d_u = 2.48$ and $d_u = 2.34$, respectively. As it is shown in Figs. 5, $\Delta\sigma(pp \rightarrow t + jet)/\sigma_{SM}$ is always positive and it is at most 20%, 6% and 0.04% for scalar, vector and tensor unparticle (Note that SM leading order cross section for s-channel cross section is 7 pb at 14 TeV). From these figures, we anticipate for the tensor and vector unparticle the cross sections are rather small for a wide region of d_u which we will not hope to detect them at LHC. Since the change in cross section of s-channel due to scalar unparticle is always positive, we can distinguish between extra dimension with KK excited W gauge boson and unparticle physics in large portion of parameters space.

Another beyond SM theory which we are going to consider is topflavor model [10, 11]. In context topflavor model, the additional W' boson can contribute to the s-channel mode of the single top production through exchange of a W' boson. The relative corrections of the topflavor model to the cross section $\sigma(pp \rightarrow t\bar{b}X)$ versus $M_{W'}$ for two values of the mixing parameters $\sin^2\phi$ at the LHC has been shown in Fig. 6. Data for $\sigma(pp \rightarrow t\bar{b}X)$ have been taken from Figs. 7 of [11]. In this figure, it is assumed that $\Delta\sigma(pp \rightarrow t\bar{b}X) = \sigma_{\text{topflavor}} - \sigma_{SM}$. From Fig. (6), we can see that the contributions of the topflavor model to single top production are very larger than other models. The topflavor model has always positive contributions to single top production at the LHC and the maximum deviation from SM

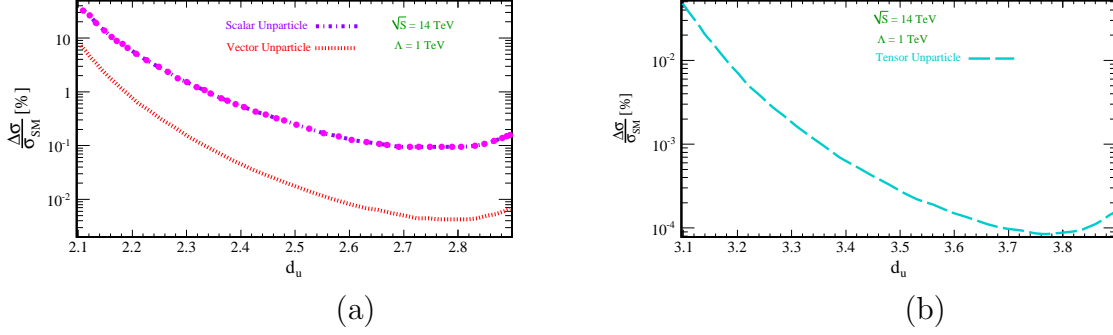


Figure 5: a) $\Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ versus scale dimension d_u in the context of unparticle physics for $\Lambda = 1$ TeV, $\lambda_0 = \lambda_1 = 1$ and $c_v = c_a$ at 14 TeV. The solid violet curve corresponds to scalar unparticle and the dotted red curve correspond to vector unparticle. b) $\Delta\sigma(pp \rightarrow t + jet)/\sigma_{SM}$ versus the scale dimension d_u in the context of unparticle physics for $\Lambda = 1$ TeV, $\lambda_2 = 1$ for tensor unparticle at 14 TeV. Data for $\Delta\sigma(pp \rightarrow t + jet)$ have been taken from Figs. 3 and 4 of [33].

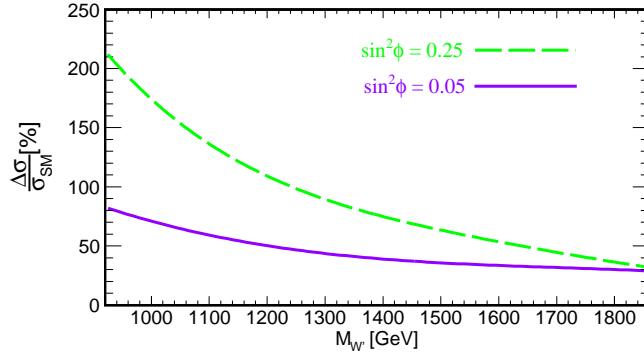


Figure 6: a) $\Delta\sigma(pp \rightarrow t\bar{b}X)/\sigma_{SM}$ versus $M_{W'}$ in the context of topflavor model for two values of the mixing parameters $\sin^2\phi$. The solid violet curve corresponds to $\sin^2\phi = 0.05$ and the dashed green curve correspond to $\sin^2\phi = 0.25$. Data for $\sigma(pp \rightarrow t\bar{b}X)$ have been taken from Figs. 7 of [11].

is 210% which is for the case of $\sin^2 \phi = 0.25$. Thus, the effects of the new gauge boson W' on the s-channel single top production might be detected at LHC and distinguishable from our model.

The effect of the supersymmetric QCD corrections to the total cross section for s-channel single top production at the LHC have been presented in [34]. It is shown that for s-channel, the supersymmetric QCD corrections are at most about 1%. Thus, we can ignore SUSY corrections in the future high precision experimental analysis for s-channel single top production at the LHC.

4 Conclusions

In extra dimension theories, if the gauge fields of the SM propagate in the bulk of the extra dimension then they will have KK excitations that can couple to the SM fermions. The masses of KK excited gauge boson will be proportional to inverse radius of compactification. In this paper, we have studied the impacts of the first KK excitation of W gauge boson on s-channel single top production at LHC. We have shown that, if the inverse of radius of compactification is in order of TeV scale or less, phenomenological effects of these states at LHC will be remarkable. The statistical uncertainty in the measurement of the cross section for this process at the LHC will be about 5.4% with an integrated luminosity of $30 fb^{-1}$ [7]. It is worthwhile to mention, the measurement of the cross section of the s-channel single top at the LHC would not necessarily lead to a deviation of V_{tb} from one or evidence of new generation of quarks. We have shown that for center of mass energy of 7 TeV if the mass of the first W_{KK} is larger than 1650 GeV, the total cross section of s-channel single top production will be reduced and deviation from SM cross section can be up to 10% which indicates that effect of large extra dimension might be detectable in this process. For center of mass energy 14 TeV, this

effect will be smaller and we need more integrated luminosity than center of mass energy of 7 TeV.

To calculate s-channel single top production, we considered three different parton distribution functions for quarks and showed that deviation from SM cross section could not arise from these effects.

We then compared our results with effects of other beyond SM theories. It is shown[30] that for LH model and topflavor model effects of new gauge boson on s-channel single top production will be constructive. Thus degeneracy between these models and our model will be distinguishable. We then discussed the effects of QCD SUSY correction and $SU(3)$ simple group model on single top production and mentioned these effects will be very small and will not be detectable at LHC. For unparticle physics model, effects of vector and tensor unparticle will be small but scalar unparticle effect will be detectable at LHC. Nevertheless this effect will be positive and so distinguishable from effect of KK excitation of W gauge boson.

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References

- [1] W. Wagner, Rept. Prog. Phys. **68** (2005) 2409 [arXiv:hep-ph/0507207]; M. Beneke *et al.*, arXiv:hep-ph/0003033.
- [2] D. Wicke, f. t. CDF and D. collaborations, arXiv:1006.1275 [hep-ex]; A. P. Heinson [CDF and D0 Collaboration], Mod. Phys. Lett. A **25** (2010) 309 [arXiv:1002.4167 [hep-ex]]; M. Chalmers;

- C. Vellidis [CDF Collaboration], arXiv:0910.3392 [hep-ex]; P. Dong [CDF and D0 Collaborations],
- [3] Q. H. Cao, J. Wudka and C. P. Yuan, Phys. Lett. B **658** (2007) 50 [arXiv:0704.2809 [hep-ph]]; Q. H. Cao, C. S. Li and C. P. Yuan, Phys. Lett. B **668** (2008) 24 [arXiv:hep-ph/0612243]; S. Heim, Q. H. Cao, R. Schwienhorst and C. P. Yuan, Phys. Rev. D **81** (2010) 034005 [arXiv:0911.0620 [hep-ph]]; Q. H. Cao, R. Schwienhorst and C. P. Yuan, Phys. Rev. D **71** (2005) 054023 [arXiv:hep-ph/0409040]; Q. H. Cao and C. P. Yuan, Phys. Rev. D **71** (2005) 054022 [arXiv:hep-ph/0408180]; R. Cortese and R. Pertronzio, Phys. Lett. **B 253**, 494 (1991). T. Stelzer and S. Willenbrock, Phys. Lett. **B 357**, 125 (1995); M. C. Smith and S. Willenbrock, Phys. Rev. **D 54**, 6696 (1996); S. Mrenna and C.-P. Yuan, Phys. Lett. **B 416**, 200 (1998); A. P. Heinson, A. S. Belyaev, and E. E. Boos, Phys. Rev. **D 56**, 3114 (1997); A. S. Belyaev, E. E. Boos and L. V. Dudko, Phys. Rev. **D 59**, 075001 (1999); T. Stelzer, Z. Sullivan, and S. Willenbrock, Phys. Rev. **D 58**, 094021 (1998); V. Barger, M. McCaskey and G. Shaughnessy, Phys. Rev. D **81** (2010) 034020 [arXiv:0911.1556 [hep-ph]]; J. A. Aguilar-Saavedra, Nucl. Phys. B **804** (2008) 160 [arXiv:0803.3810 [hep-ph]].
- [4] Q. H. Cao, R. Schwienhorst, J. A. Benitez, R. Brock and C. P. Yuan, Phys. Rev. D **72** (2005) 094027 [arXiv:hep-ph/0504230]; S. Dawson, Nucl. Phys. **B 249**, 42 (1985); S. Willenbrock and D. Dicus, Phys. Rev. **D 34**, 155 (1986); C.-P. Yuan, Phys. Rev. **D 41**, 42 (1990); R. K. Ellis and S. Parke, Phys. Rev. **D 46**, 3785 (1992); D. O. Carlson and C.-P. Yuan, “Probing New Physics from the Single Top Production”, Particle Phys. & Phen. 1995, 172 (1995); hep-ph/9509208; D. Carlson, Ph.D. thesis, Michigan State University, MSUHEP-050727, August 1995; G. Bordes and B. van Eijk, Z. Phys. **C 57**, 81 (1993).

- G. Bordes and B. van Eijk, Nucl. Phys. **B 435**, 23 (1995); T. Stelzer, Z. Sullivan, and S. Willenbrock, Phys. Rev. **D 56**, 5919 (1997); J. M. Campbell, R. Frederix, F. Maltoni and F. Tramontano, JHEP **0910** (2009) 042 [arXiv:0907.3933 [hep-ph]]; P. Motylinski, Phys. Rev. D **80** (2009) 074015 [arXiv:0905.4754 [hep-ph]].
- [5] G. Ladinsky and C.-P. Yuan, Phys. Rev. **D 43**, 789 (1991); S. Moretti, Phys. Rev. **D 56**, 7427 (1997); Q. H. Cao, arXiv:0801.1539 [hep-ph]; S. Zhu, arXiv:hep-ph/0109269; T. M. P. Tait, Phys. Rev. D **61** (2000) 034001 [arXiv:hep-ph/9909352].
- [6] A. P. Heinson, Proceedings of the 2nd International Conference on B Physics and CP Violation. Honolulu, Hawaii, 24-27 March, 1997; Editors : T. E. Browder, F. A. Harris and S. Pakvasa; hep-ex/9707026.
- [7] “ATLAS detector and physics performance. Technical design report. Vol. 2,” CITATION = ATLAS-TDR-15;
- [8] Z. Sullivan, Phys. Rev. D **66** (2002) 075011 [arXiv:hep-ph/0207290]; N. Kidonakis, Phys. Rev. D **75** (2007) 071501 [arXiv:hep-ph/0701080]; Y. B. Liu, J. F. Shen and X. L. Wang, arXiv:hep-ph/0610350; N. Kidonakis, Phys. Rev. D **74** (2006) 114012 [arXiv:hep-ph/0609287]; C. X. Yue, S. Yang and L. H. Wang, Europhys. Lett. **76** (2006) 381 [arXiv:hep-ph/0609107]; M. Frank and I. Turan, Phys. Rev. D **74** (2006) 073014 [arXiv:hep-ph/0609069]; Q. H. Cao and J. Wudka, Phys. Rev. D **74** (2006) 094015 [arXiv:hep-ph/0608331].
- [9] E. Boos, V. Bunichev, L. Dudko and M. Perfilov, Phys. Lett. B **655** (2007) 245 [arXiv:hep-ph/0610080].

- [10] E. Malkawi, T. M. P. Tait and C. P. Yuan, Phys. Lett. B **385** (1996) 304 [arXiv:hep-ph/9603349]; D. J. Muller and S. Nandi, Phys. Lett. B **383** (1996) 345 [arXiv:hep-ph/9602390].
- [11] T. M. P. Tait and C. P. P. Yuan, Phys. Rev. D **63** (2001) 014018 [arXiv:hep-ph/0007298].
- [12] F. del Aguila, J. de Blas and M. Perez-Victoria, arXiv:1005.3998 [hep-ph]; D. Gherson, Phys. Rev. D **76** (2007) 043507 [arXiv:hep-ph/0702183]; C. P. K. Altes, arXiv:hep-ph/0307368; G. Sigl, arXiv:hep-ph/0207254; P. Nath and M. Yamaguchi, Phys. Rev. D **60**, 116006 (1999) and Phys. Rev. D **60**, 116004 (1999); M. Masip and A. Pomarol, Phys. Rev. D **60**, 096005 (1999) ; W.J. Marciano, Phys. Rev. D **60**, 093006 (1999); L. Hall and C. Kolda Phys.Lett. B **459** 213, (1999); R. Casalbuoni, S. DeCurtis and D. Dominici, Phys.Lett. B **460** 135, (1999) ; R. Casalbuoni, S. DeCurtis, D. Dominici and R. Gatto, Phys.Lett. B **462** 48, (1999); A. Strumia, hep-ph/9906266; C. D. Carone, Phys. Rev. D **61**, 015008 (2000); F. Cornet, M. Relano and J. Rico, Phys. Rev. D **61**, 037701 (2000); T. G. Rizzo, hep-ph/9909232; I. Antoniadis, K. Benalki and M. Quirós, hep-ph/9905311; E. Accomando, I. Antoniadis and K. Benalki , hep-ph/9912287; P. Nath, Y. Yamada and M. Yamaguchi, hep-ph/9905415.
- [13] M. Pangilinan, “Top Quark Produced Through the Electroweak Force: Discovery Using the Matrix Element Analysis and Search for Heavy Gauge Bosons Using Boosted Decision Trees,”
- [14] A. Datta and X. Zhang, Phys. Rev. D **61** (2000) 074033 [arXiv:hep-ph/9912450].
- [15] L. J. Hall and C. F. Kolda, Phys. Lett. B **459** (1999) 213 [arXiv:hep-ph/9904236].

- [16] T. Banks, M. Dine and A. E. Nelson, JHEP **9906** (1999) 014 [arXiv:hep-th/9903019].
- [17] A. Delgado, A. Pomarol and M. Quirós, hep-ph/9911252; T.G. Rizzo and J.D. Wells, Phys. Rev. **D 61**, 016007 (2000);
- [18] G. Marandella and M. Papucci, Phys. Rev. D **71** (2005) 055010 [arXiv:hep-ph/0407030]; L. Hall and C. Kolda Phys.Lett. **B 459** 213, (1999); R. Barbieri and A. Strumia, Phys.Lett. **B 462** 144, (1999); R. Shekar Chivukula and Nick Evans, Phys.Lett. **B 464** 244, (1999); A. Datta and X. Zhang, Phys. Rev. **D 61**, 074033 (2000).
- [19] A. Pomarol and M. Quirós, Phys. Lett. **B 438**, 255 (1998) ; I. Antoniadis, S. Dimopoulos, A. Pomarol and M. Quirós, Nucl. Phys. **B 544**, 503 (1999); A. Delgado, A. Pomarol and M. Quirós, Phys. Rev. **D 60**, 095008 (1999).
- [20] H. C. Cheng, arXiv:1003.1162 [hep-ph].
- [21] T. Appelquist, H. C. Cheng and B. A. Dobrescu, Phys. Rev. D **64**, 035002 (2001) [arXiv:hep-ph/0012100]; T. Appelquist and H. U. Yee, Phys. Rev. D **67**, 055002 (2003) [arXiv:hep-ph/0211023].
- [22] A. Datta, P. J. O'Donnell, Z. H. Lin, X. Zhang and T. Huang, Phys. Lett. B **483** (2000) 203 [arXiv:hep-ph/0001059].
- [23] G. Aad *et al.* [The ATLAS Collaboration], arXiv:0901.0512 [hep-ex].
- [24] W. K. Tung, Acta Phys. Polon. B **33** (2002) 2933 [arXiv:hep-ph/0206114].
- [25] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Eur. Phys. J. C **63** (2009) 189 [arXiv:0901.0002 [hep-ph]].

- [26] S. Alekhin, J. Blumlein, S. Klein and S. Moch, arXiv:0908.3128 [hep-ph].
- [27] M. Beneke *et al.*, arXiv:hep-ph/0003033.
- [28] N. Arkani-Hamed, A. G. Cohen, E. Katz, A. E. Nelson, *JHEP***0207**(2002)034.
- [29] T. Han, H. E. Logan, B. McElrath and L. T. Wang, *Phys. Rev. D***67**(2003)095004.
- [30] C. X. Yue, L. Zhou and S. Yang, Eur. Phys. J. C **48** (2006) 243 [arXiv:hep-ph/0604001].
- [31] D. E. Kaplan and M. Schmaltz, *JHEP* **0310**(2003)039; M. Schmaltz, *JHEP* **0408**(2004)056.
- [32] T. Han, H. E. Logan, and L. T. Wang, *JHEP* **0601**(2006)099.
- [33] A. T. Alan, N. K. Pak and A. Senol, Europhys. Lett. **83** (2008) 21001 [arXiv:0710.4239 [hep-ph]].
- [34] J. J. Zhang, C. S. Li, Z. Li and L. L. Yang, Phys. Rev. D **75** (2007) 014020 [arXiv:hep-ph/0610087].